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Strength of adhesive aided SPR joint for AM50 magnesium alloy sheets

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Abstract

In order to reduce weight of a vehicle, application of light metals has increased. Magnesium alloy is very light and has high specific strength compared to other structural metals. SPR (Self Piercing Rivet) joining has been applied mainly for an aluminum alloy in motor industries. However, application of SPR joining to a magnesium alloy is very limited. In this study, SPR joining was carried out with AM50 magnesium alloy sheets. According to the result of joining experiment, cracking easily occurred at the lower sheet due to poor formability of the alloy. Static and fatigue strength of the joint were evaluated under shear tensile loading condition. The crack introduced in SPR process affects on strength of the joint. As a practical way to solve the problem, adhesive aided SPR joining was proposed. Adhesive was spread on the surface and then SPR joining was conducted before its hardening. The maximum shear tensile load of the joint increased by using an adhesive and was strongly influenced by kind of adhesive used. Fatigue strength also improved by using an adhesive. It is proposed that control for deformation due to SPR process at the edge of the joining area could be effective to improve the strength.

Keywords: SPR (Self Piercing Rivet) joint; Adhesive aided SPR joint; Magnesium alloy

1. Introduction

Since problems of pollution and saving fuel become more severe, reduction of weight of a vehicle is one of the most important tasks in mechanical engineering. Then application of light metals, such as

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aluminum alloy or magnesium alloy increases in motor industries. The most suitable welding and joining method should be selected following change in materials used [1]. SPR (self Piecing Rivet) joining is widely used in motor industry for mainly aluminum alloys sheet [2], [3]. SPR joining process is schematically shown in Fig.1. SPR joint usually shows high strength and is applicable to dissimilar materials joining. Another interesting advantage of SPR joining for application in a motor industry is sealing property. Leakage of moisture and water at joining part does not occur because a lower sheet is not completely penetrated in SPR joining. This is also good for protection from corrosion. Magnesium alloy is very light weight metal and has high specific strength. Application of magnesium alloy in motor industry is increasing due to those advantages. However, application of SPR joining for a magnesium alloy is very limited [4], [5]. One reason is that cracking easily occurred during joining process due to poor formability of the alloy. In previous reports, SPR joining was conducted at elevated temperature to solve the cracking problem. However, in practical application, heating process has problem on productionability and material point of view. In this paper, adhesive aided SPR joining of magnesium alloy was studied as one of practical solutions. Static and fatigue strength of the joints were evaluated under shear tensile loading condition.

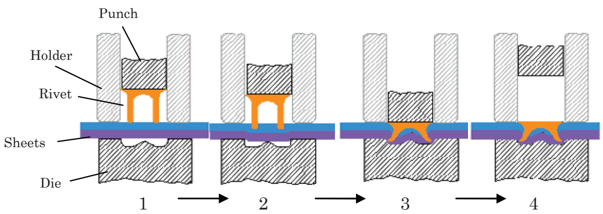


Fig.1 Schematic illustration of SPR joining process.

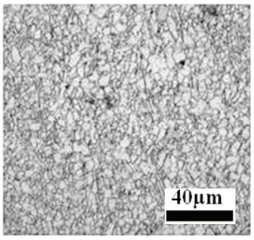


Fig.2 Microstructure of AM50.

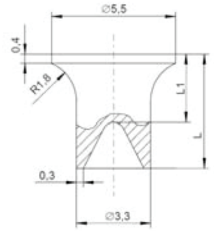


Fig.3 Geometry of the rivet (RIBE, ALFORM RIFIT, Hv=170)

Table 1 Chemical composition of AM50.

Al	Mn	Zn	Si	Fe	Cu	Ni	Cr	Mg
5.0	0.29	0.039	0.009	<0.002	<0.002	0.002	-	bal.

Table 2 Mechanical properties of AM50.

Young's modulus, GPa	Tensile strength, MPa	0.2% proof stress, MPa	Elongation, %
45	300	198	14.4

Table 3 Mechanical properties of adhesives used.

Adhesive	Elastic modulus, MPa	Tensile strength, MPa	Elongation, %	Shear tensile strength, MPa
A	1034-1207	27.6-31.0	5-15	20.7-24.1
B	483-690	22.1-26.2	30-60	15.9-19.3
C	517-690	18.6-20.7	100-125	12.0-15.5
D	-	18-28	-	-

2. Experimental procedure

2.1 Material and specimen used

AM50 magnesium alloy rolled sheet with thickness of 0.8 mm was used as a material used in the present study. Microstructure, chemical composition and mechanical properties of the material used are shown in Fig.2 , Table 1 and Table 2, respectively. Specimen was cut to the size of 20 ×100 mm for the static strength test and 25 × 100 mm for the fatigue strength test. In the SPR joining test, a commercial aluminum rivet (RIBE ALUFORM RIFIT type, H_V;170) has been used. Geometry of the rivet is shown in Fig.3. Four types of adhesives were used for adhesive aided SPR joining. Properties of the adhesives are shown in Table 3. Adhesive A, B and C are methacrylate type, and D is epoxy type adhesives.

2.2 SPR and adhesive aided SPR joining

SPR joining experiment was conducted with tensile testing machine (Shimadzu, Auto-graph AGX). Jigs for the SPR joining were designed and attached to the tensile testing machine. The rivet was held in the upper jig and was pushed into the specimen with cross head speed of 100 mm/min. Plunge depth was fixed to 4.2 mm from the specimen surface of the top sheet. Cross head displacement and load were recorded during SPR joining process. In the adhesive aided SPR joining, an adhesive was spread on the specimen surface and set it to the SPR joining machine before hardening of the adhesive. Then SPR joining was conducted with the same conditions of SPR joining as shown in above and kept the joint at room temperature until that the adhesive is completely hardened.

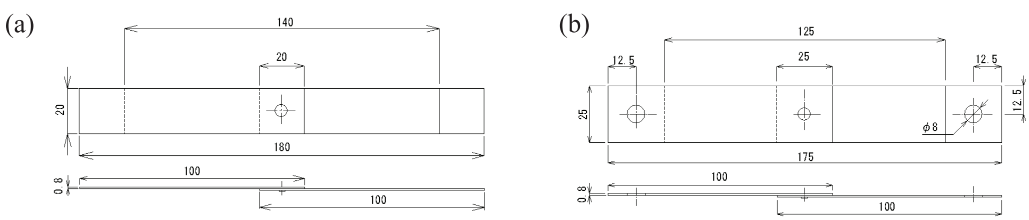


Fig.4 Geometry of the specimens for (a) static tensile shear test and (b) fatigue test.

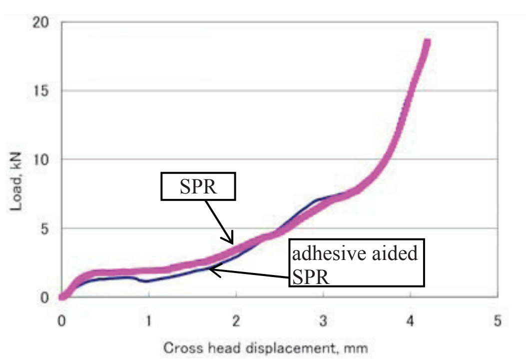
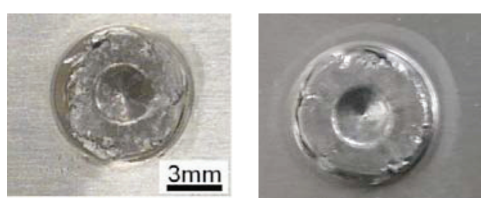


Fig.5 Load – displacement curves during SPR and adhesive aided SPR joining processes.



(b) SPR joint

(a) Adhesive aided SPR joint

Fig.6 Back side view of joining part in a lower sheet.

2.3 Evaluation of strength for the joints

Shear tensile test was carried out with displacement speed of 1 mm/min to evaluate the static strength of the joints. Fatigue strength of the joints was also evaluated under shear tensile loading condition. An electro- hydraulic servo fatigue test machine (Shimadzu, SERVO PULSER) was used. Fatigue loading was applied with sinusoidal wave form, load ratio R=0.1 and frequency of 10Hz. The definition of the failure of the joint in the present tests is occurrence of separation to two pieces. Specimen shapes for static strength test and fatigue strength test are shown in Fig.4.

2. Result and discussion

Figure 5 shows examples of load – cross head displacement curves during SPR and adhesive aided SPR joining processes. In adhesive aided SPR joining shown in the figure, C type adhesive was used. As shown from Fig.5, effect of adhesive adding on the curves is negligible. Back side views of SPR and adhesive aided SPR joints are shown in Fig6. Cracking was observed in the lower sheet for both in SPR and adhesive aided SPR joints.

Result of tensile shear test is shown in Fig.7. The maximum shear tensile loads obtained in adhesive aided SPR joints are higher than that of SPR joint (without adhesive). However, the maximum shear tensile load of adhesive aided SPR joints strongly depends on adhesive type used. The highest value of the maximum shear tensile load was obtained in adhesive aided SPR joint joined with C type adhesive. Then C type adhesive was chosen to make a specimen of adhesive aided SPR joint for the fatigue strength test in the following. Comparison of load – cross head displacement curves during shear tensile tests between SPR joint and adhesive aided SPR joint with C type adhesive are shown in Fig.8. In the case of SPR joining (without adhesive), load increased with increasing the displacement then load decreased slowly to the final break of the joint. The degradation of load after the maximum load is corresponding to deformation of the specimen around the rivet and pulling off of the rivet. On the other hand, in the case of adhesive aided SPR joint, load increased linearly with increasing the displacement until the maximum load, then suddenly, load was dropped to the certain value which is similar to the maximum load observed in SPR joint (without adhesive). In finally, load increased once then decreased un-continuously to the separation of the joint. It is considered that the first dropping of load just after the maximum load is

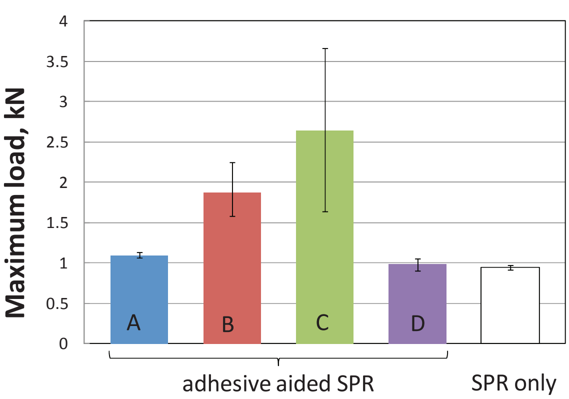


Fig.7 The maximum shear – tensile load for SPR and adhesive aided SPR joints.

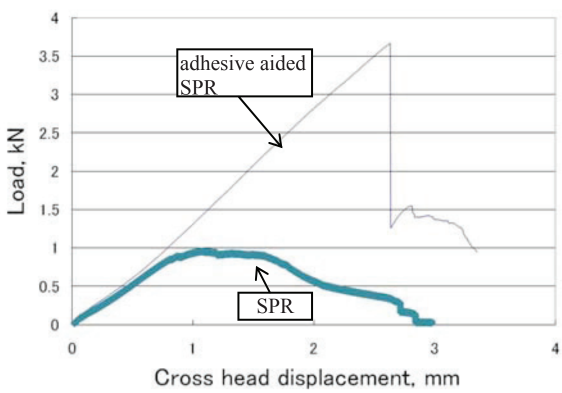


Fig.8 Load - displacement curves during tensile shear test for SPR joint and adhesive aided SPR joint with adhesive type C.

corresponding to occurrence of cracking at the edge of the adhesive bonded region. It is speculated that the second load drop is corresponding to the final separation of the joint. Strength of an adhesive used is dominant on the maximum load, however, a rivet also affects on fracture process in the case of adhesive aided SPR joint.

Results of fatigue strength test of the joints are shown in Fig.9. Adhesive aided SPR joint shows higher fatigue strength compared to SPR joint (without adhesive). In the case of SPR joint tested in higher applied load region, joints were broken at the upper sheet. In lower applied load condition, the joints were broken at the lower sheet as shown in Fig.10. Fatigue crack initiated from the crack introduced during SPR joining process, according to the observation of the fracture surface as shown in Fig.10(b). In the case of adhesive aided SPR joint tested at high applied load region, joints are broken in the adhesive layer and fatigue crack did not propagate in the specimen sheet as shown in Fig.11 (a). However, in lower applied load region, adhesive aided SPR joints were broken by fatigue crack propagation in a lower sheet, as shown in Fig.11(b). It is considered that the fatigue crack initiated from a crack introduced during SPR joining process. However, at the beginning, fatigue crack initiated from the edge of adhesive bonded area

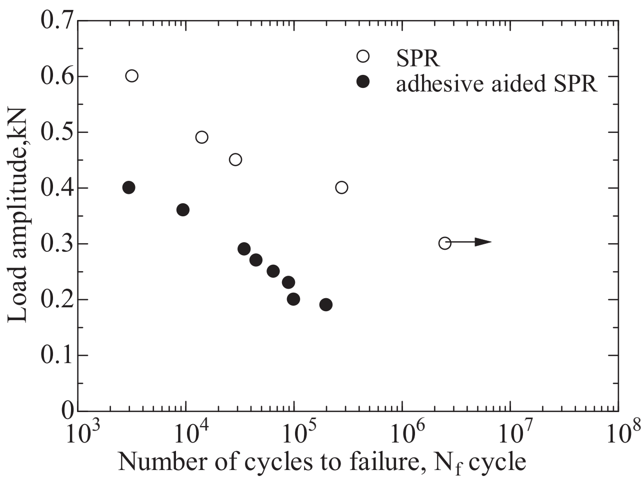
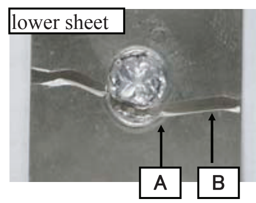
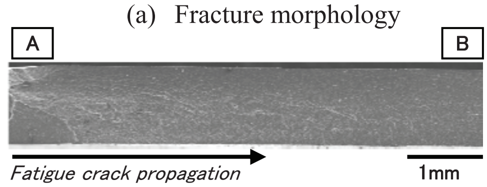


Fig.9 Results of fatigue test for SPR joint and adhesive aided SPR joint.

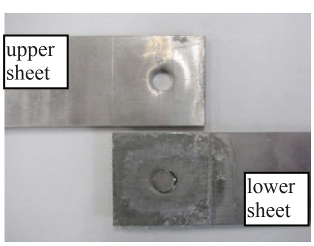


(a) Fracture morphology

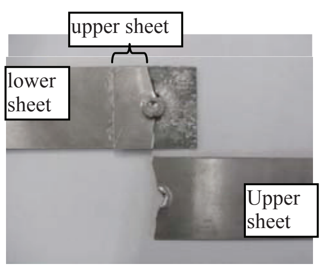


(b) fracture surface

Fig.10 SPR joint after the fatigue test. (Load amp.=0.23kN, N_f=5.8×10^4 cycles).

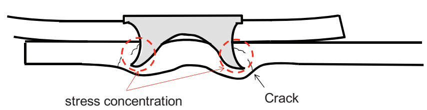


(b) Load amp.=0.4kN, N_f=2.7×10^5 cycles

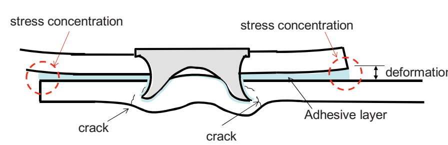


(a) Load amp.=0.3kN, N_f=2.5×10^6 cycles

Fig.11 Fracture morphology of adhesive aided SPR joint after the fatigue test.



(a) SPR joint



(b) adhesive aided SPR joint

Fig.12 Schematic illustration of joining region.

for the adhesive aided SPR joint. Strength and fracture behavior of adhesive is dominant on those of adhesive aided SPR joint. Joining part for SPR joint and adhesive aided SPR joint are schematically shown in Fig.12. In the case of SPR joint without adhesive, high stress concentration occurred around the rivet. In the case of adhesive aided SPR joint, high stress concentration point shifted to the edge of adhesive bonded area. It is well known that strength of the adhesive joint is depending on the thickness of adhesive layer [6]. In the adhesive aided SPR joining, specimen was deformed during SPR joining process. Thickness of the adhesive layer at the edge of adhesive bonding region changed due to the deformation of the specimen. It could be proposed that control of deformation of the specimen during SPR joining is necessary to improve strength of adhesive aided SPR joint.

Summary

SPR joint and adhesive aided SPR joint were applied to AM50 magnesium alloy rolled sheet with thickness of 0.8mm. Cracks were observed at the joining area in lower sheet for both SPR joint and adhesive aided SPR joint. The maximum shear tensile loads of adhesive aided SPR joints were higher than that of SPR joint. Strength of the joint was depending on an adhesive used. Fatigue strength test under shear tensile loading condition was carried out for the SPR joint and the adhesive aided SPR joint. The adhesive aided SPR joint showed higher fatigue strength compared to SPR joint. It is speculated that controlling of gap at the edge of adhesive bonded region due to deformation of the sheet occurred during SPR process could improve strength of adhesive aided SPR joint.

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